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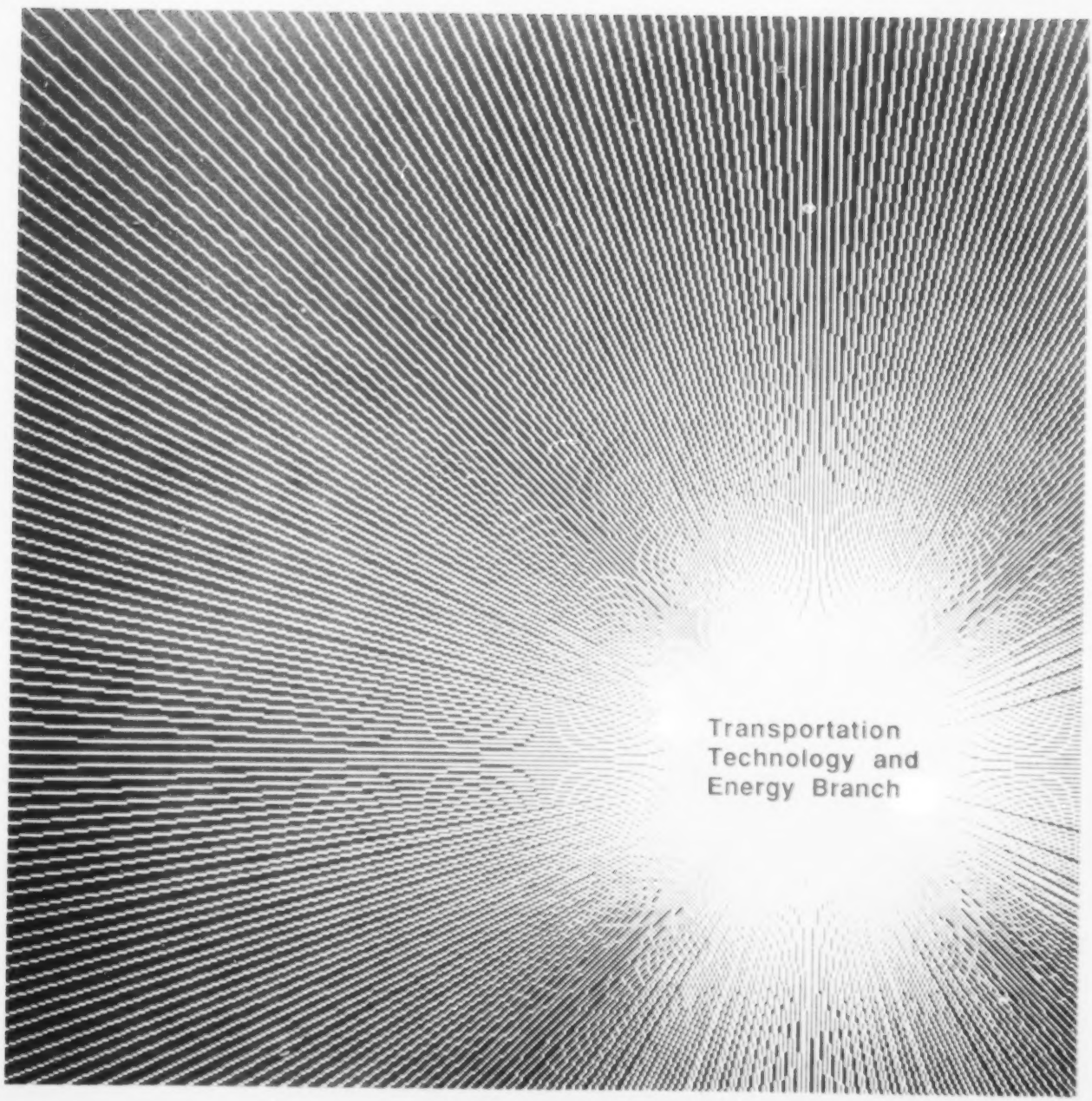

Assessment of Automatic Vehicle Location (AVL) Technologies for Taxicab Applications in the Metropolitan Toronto Area

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Assessment of Automatic Vehicle Location (AVL) Technologies for Taxicab Applications in the Metropolitan Toronto Area

Prepared by: Lamberto Gomes

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Abstract: The taxi emergency location and dispatching project was initiated by the Transportation Technology and Energy Branch of the Ministry of Transportation of Ontario to assist in improving the safety and efficiency of taxicab operations in Metropolitan Toronto. This report provides an assessment of Automatic Vehicle Location (AVL) technologies and systems for urban applications. The needs of taxicab companies and selected public sector agencies are analyzed. The report includes conclusions and recommendations.

Key words: Automatic vehicle location systems, Transit operations, Driver communications, Land-based radio location systems, Satellite-based radio location systems, Signpost/ odometer-based systems

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Assessment of Automatic Vehicle Location (AVL) Technologies for Taxicab Applications in the Metropolitan Toronto Area

L. Gomes

Transportation Control Technology and Systems Office
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CONTENTS

PAGE

ACKNOWLEDGEMENTS v

GLOSSARY vi

1/ INTRODUCTION 1

2/ LOCATION TECHNIQUES, SYSTEM FEATURES, AND COSTS 4
2.1/ Dead Reckoning and Dead Reckoning with Map Matching 4
2.2/ Proximity Detection Signpost 6
2.3/ Satellite-Based Location Systems 7
2.4/ Ground-Based Radio Location Systems 9
2.5/ Hybrid Location Techniques 11
2.6/ Comparison of Dispatch and AVL Systems 11
2.7/ Benefits of an AVL System 13

3/ SURVEY OF POTENTIAL USERS 14

4/ METRO TORONTO'S AVL REQUIREMENTS 15

5/ ANALYSIS OF USER NEEDS 16

6/ ASSESSMENT OF COMMERCIAL EMERGENCY LOCATION SYSTEMS 17

7/ CONCLUSIONS AND RECOMMENDATIONS 19

BIBLIOGRAPHY 20

APPENDICES
1/ Needs Requirements Questionnaire for Taxi Cabs 21
2/ Technical Details of the Systems Looked at in This Study 36
3/ Summary of Taxi Interview Findings 52

TABLES

PAGE

1/ Comparative Analysis of AVL Systems for Urban Application 12
2/ Potential Users of AVL Technology 14

FIGURES

1/ Automatic Vehicle Location System 2
2/ Dead Reckoning Position Determination 5
3/ Dead Reckoning with Map Matching 5
4/ TTC Signpost System 6
5/ WAVM/TMI – Road KIT System 8
6/ Projected GPS Receiver Cost 9
7a/ Time-Difference Automatic Vehicle Locating Systems 10
7b/ The Probable Evolution of Loran-C Receiver Costs 10
8/ Reverse Loran (REVLOR) System Overview 11
9/ Similarities Between Cabmate Dispatch and AVL Systems 13
10/ LOJACK System 37
11a/ QUIKTRAK System 39
11b/ QUIKTRAK Central Computer System 40
12/ Major Elements of the Teletrac System 42
13/ DATATRAK System 43
14/ Detroit AVL System 44
15/ GPS Location Technique 45
16/ V-Trak System 46
17/ DFLS Conceptual Overview 48
18/ The AVL System 49
19/ The Australian VDS System 50
20/ System Block Diagram for Metro Ambulance Services 51

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Project Steering Committee:
Bruce Bell, Taxicab Association Toronto
John Carnduff, Metro Works Department
Richard Ellis, Metro Toronto Police Department
Lamberto Gomes, MTO
Richard Grant, Metro Roads and Traffic
Gabriel Heti, MTO
John Howard, Metro Parks and Property
Keeva Lane, Metro Licensing Commission
Sheila Marshall, Metro Licensing Commission
Dan Perlstein, Department of Ambulance Services
Victor Portelli, Metro Parks and Property Department

User Group:
B.W.A. Crosland, City of Etobicoke, Works Department
Maurice Dinneen, City of Toronto, Purchasing and Supply Department
Bill Forrest, Director of Administration and Fleet Operations, City of Scarborough
W.R. Hamilton, Commissioner of Works, City of York
George Parry, Mechanical Superintendent, Works Department, City of York
Anthony Pellegrino, City of Toronto, Department of Public Works
John Thomas, Borough of East York, Traffic and Parking Department
Jack Waghorn, Director of Operations, City of York
E.C. Walton, Deputy Commissioner of Operations, City of Scarborough
Alan Wolfe, Deputy Commissioner, Public Works Department, City of North York

GLOSSARY

Tracking:	Location of a vehicle at more frequent time intrervals than the normal location response time
Monitoring:	Retrieval of information on specific vehicle functions such as temperature, fuel consumption, cargo condition
Route Guidance:	Information given to the driver to follow or select the best route among a given set of points.
Navigation:	Information on position and directions to destination

1/ INTRODUCTION

This feasibility study was carried out by the Transportation Control Technology and Systems Office between October 1989 and September 1991. It evolved from initial efforts made by the Metro Licensing Commission, a Metropolitan Toronto municipal organization with jurisdiction over the city's taxi industry, to consider various automatic vehicle location systems to assist taxi drivers in distress.

It was recognized that an emergency vehicle location system could be of benefit to a large number of private and public sector groups. The original project steering committee was thus expanded to include Metro Ambulance, Metro Police, various municipal works departments, Ontario Provincial Police, Toronto Transit Commission's Paratransit Agency, and cartage trucks.

There were eight steps in the methodology of the study: preparation and mailing of two sets of questionnaires, one directed to the taxi industry and the other to the public sector; a literature search, consultation, and interviews with potential users; evaluation of responses to the questionnaires and further consultation for clarification; definition of key parameters for the selection criteria; review of existing and upcoming commercial systems and development and alternative scenarios; on-site evaluation where feasible and consultation with system suppliers; and, finally, recommendations and negotiations for a pilot demonstration, which are contained in this report.

An automatic vehicle location (AVL) system enables users to determine and display the positioning and status of vehicle(s) throughout a coverage area. The display terminal can be located in the vehicle or at a central facility.

The vehicle on-board segment consists of:

- a transponder (transmitter plus receiver), or a transmitter or a receiver only;
- antennas;
- an on-board processor with or without display screen (where required);
- trip recorders, odometers, sensors, gyro, and compass (where required).

The control centre segment consists of:

- central processor(s);
- track display station(s);
- peripheral(s);
- communications subsystem.

The communications system segment consists of:

- an internal communication network (generally of a dedicated nature) such as an in-vehicle communications subsystem or a central facility communications subsystem (e.g., a local area network).

- an external communication link, which could be of a dedicated or shared nature such as:
  - infra-red subsystem;
  - radio communications subsystem;
  - satellite communications subsystem.

Any of the communications systems can be designed for localized, area-wide, or region-wide applications. A typical example of localized, or close-range, applications would be systems for fixed or predetermined routes, such as buses, and other public transportation vehicles. Area-wide (urban-range) applications would be systems for taxis and municipal fleets. Region-wide (continental or inter-continental ranges) applications would suit the trucking industry.

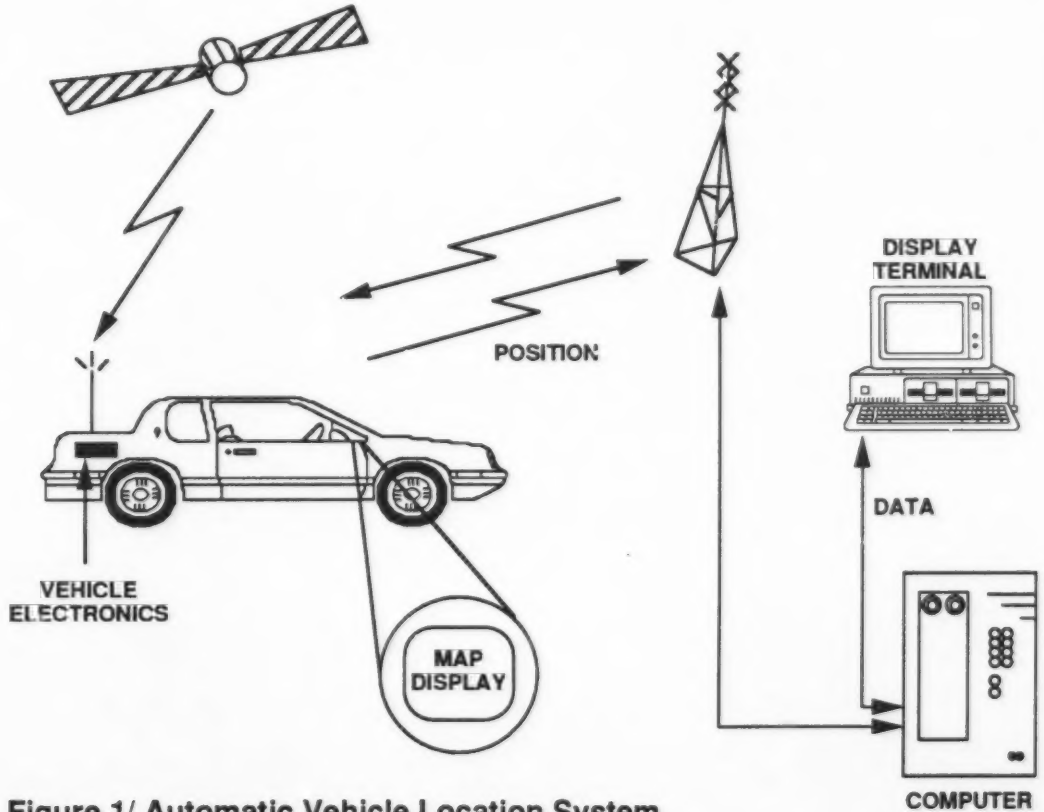


Figure 1/ Automatic Vehicle Location System

Of importance to this study are the system considerations for urban-range applications. Compared to close-range systems, the infrastructure costs for urban-range systems are lower, but the radio frequency spectrum constraints are higher, which invariably limits the system capacity. Costs and limitations of region-wide (non-urban) systems are different and beyond the scope of this project.

AVL systems can be broadly divided into three categories: autonomous (non-radio location) systems, non-autonomous (radio location) systems, and hybrid systems.

Autonomous systems do not require on-line communication for the calculation of a vehicle's position. For emergency alert at a central location however, a communications link is required. Autonomous systems are structured to provide positioning data. Dead reckoning and dead reckoning with map matching systems and proximity detection (also known as signpost or wayside beacon) systems are in this category. Non-autonomous systems generally do require an on-line communication system for the calculation of a vehicle's position. Non-autonomous systems can be structured for positioning or monitoring. Satellite location systems and ground-based location systems fall into this category.

There are also hybrid location systems, which incorporate both autonomous and non-autonomous elements.

2/ LOCATION TECHNIQUES, SYSTEM FEATURES, AND COSTS

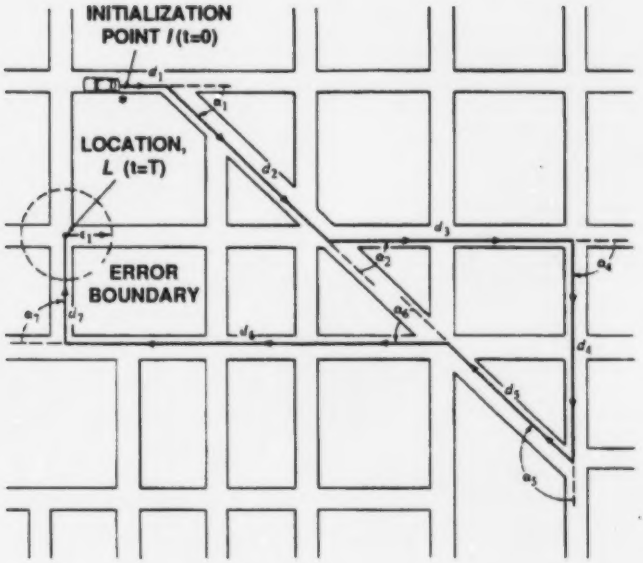
2.1/ Dead Reckoning and Dead Reckoning with Map Matching

Dead reckoning and dead reckoning with map matching systems determine location coordinates by calculating the distance and direction travelled by a vehicle from an initial start position (reference position). Distance is measured by the odometer or a similar device; direction is measured by a magnetic or electronic compass or a gyroscope. Dead reckoning systems are prone to accumulating errors during the travel, specially at turns, thus severely jeopardizing their position accuracy. Errors can be corrected en route by reinitializing at designated reference points, or by map matching techniques, which correct errors by matching a vehicle's path to a stored map of the road network.

These systems are essentially geared to provide positioning information. The driver may retrieve the stored information either audibly or visually. Should this information be required at the control centre, an on-line communications system is required. Though the accuracy of dead reckoning systems is satisfactory for urban applications, their high on-board equipment costs, (approximately $3000 per vehicle) together with the added cost of map digitization and a communication system, render it unattractive for fleet management. New solutions based on centralized processing operations (i.e., all location calculations carried out at the central facility), cost-effective display technology, and efficient communication schemes are beginning to lower the cost barriers, thus making such an operation more attractive for fleet management.

Used in conjunction with non-autonomous systems, dead reckoning with map matching systems could overcome the accuracy limitations pertinent to radio-based location systems.

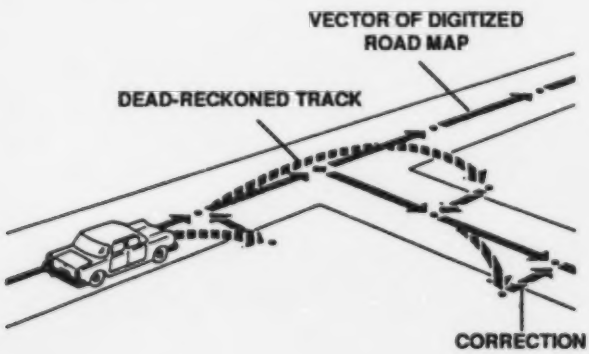
Figures 2 and 3 illustrate the dead reckoning principle.



Source: Edward N. Skomal

Figure 2/ Dead Reckoning Position Determination

Initialization of the vehicle at time t = a (point of reference)
As the vehicle moves, distance d_i and turn angles α_i are added vectorially
Along the route, errors in measuring d_i and α_i accumulate
To correct these errors, the position must be reinitialized.



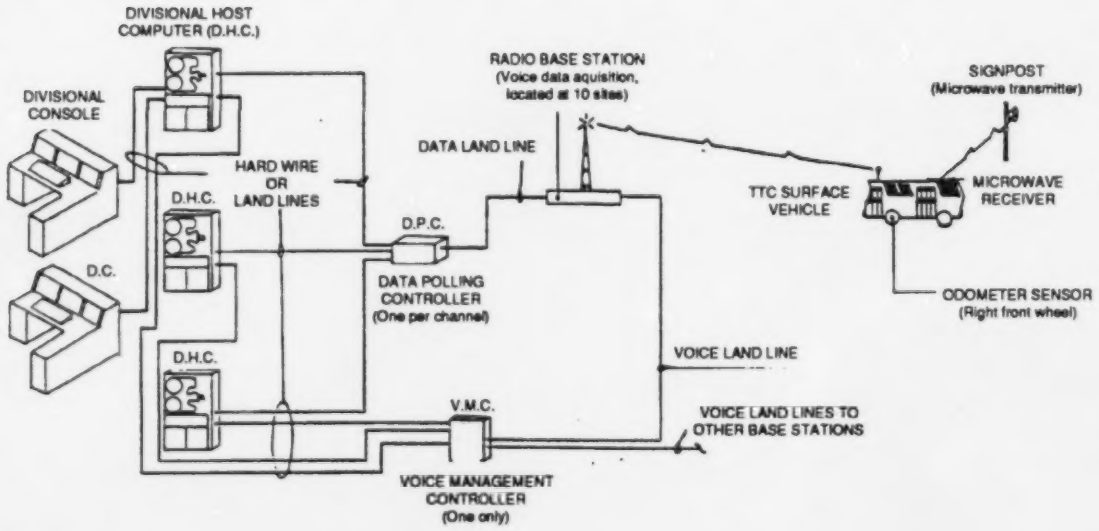
Source: J. Walker

Figure 3/ Dead Reckoning with Map Matching

2.2/ Proximity Detection Signpost

Vehicle location is obtained through an interaction between the vehicle equipped with an on-board receiver and the wayside communications infra-structure also known as signposts. The signpost identification signal is passed on to the vehicle's on-board receiver to determine and store the site location and the time. Data thus stored may be transferred to the control centre via a communication link. The odometer sensor measures the distance travelled by vehicles between signposts.

High system costs, due to the wayside infra-structure, make it unattractive for off-route location application as envisaged in this study. However, as the Toronto Transit Commission (TTC) operates such a system (Figure 4) in the Metropolitan Toronto Area, substantial savings may be realized if the infrastructure could be shared to support hybrid system architecture.



Source: CIS Technical Manual, Toronto Transit Commission

Figure 4/ TTC Signpost System

2.3/ Satellite-Based Location Systems

Location with satellite-based systems is obtained by triangulation or trilateration methods applied to radio signals. These systems may be structured to provide either positioning or monitoring data, or both. Satellite-based location systems may be active or passive.

The Global Positioning System (GPS) is an example of a passive satellite system. The GPS mode of operation is simple: signals from at least three satellites are captured by the in-vehicle GPS receiver to determine the vehicle's location. Location coordinates are obtained by triangulation.

When fully deployed, GPS's constellation will consist of 24 satellites orbiting around the world. It is expected that by 1992, North America will have six to eight satellites visible at all times. GPS is supported by the U.S. government and user fees are waived at the present time. The update rate is high and the number of simultaneous users virtually unlimited. However, tests to date indicate that GPS does experience loss of signals in highrise built-up areas due to multipath and shadowing effects. Application in urban areas is therefore severely hampered by site topography. Developments are in progress to minimize the multipath and shadowing effects by integrating the GPS on-board receiver with a dead-reckoning device. Accuracy is reported to be around 50 metres and, in differential mode, five metres. Differential GPS is a concept that uses the position information of a known reference receiver to decrease the errors common to all users over a wide geographical area. It is expected that by 1993, most GPS receivers will be able to interconnect with Mobile Satellite (MSAT), UHF, VHF or cellular-based two-way radio communications systems to allow a monitoring capability.

Fostered by the ministry's WAVM project, TMI's satellite-based two-way communication and vehicle location system (see Figure 5), called RoadKIT, has a GPS receiver in its vehicle on-board terminal to provide positioning capability in 1992.

Figure 6 uses estimates obtained from the industry to illustrates the evolution of GPS receiver costs.

GPS receivers are currently (1991) being marketed at $650 for large quantities, which is considerably less than the initial $3500. The cost of an integrated on-board receiver, with differential capability, will eventually dictate the level of acceptance of a GPS system for fleet management operations, navigation, and route guidance applications.

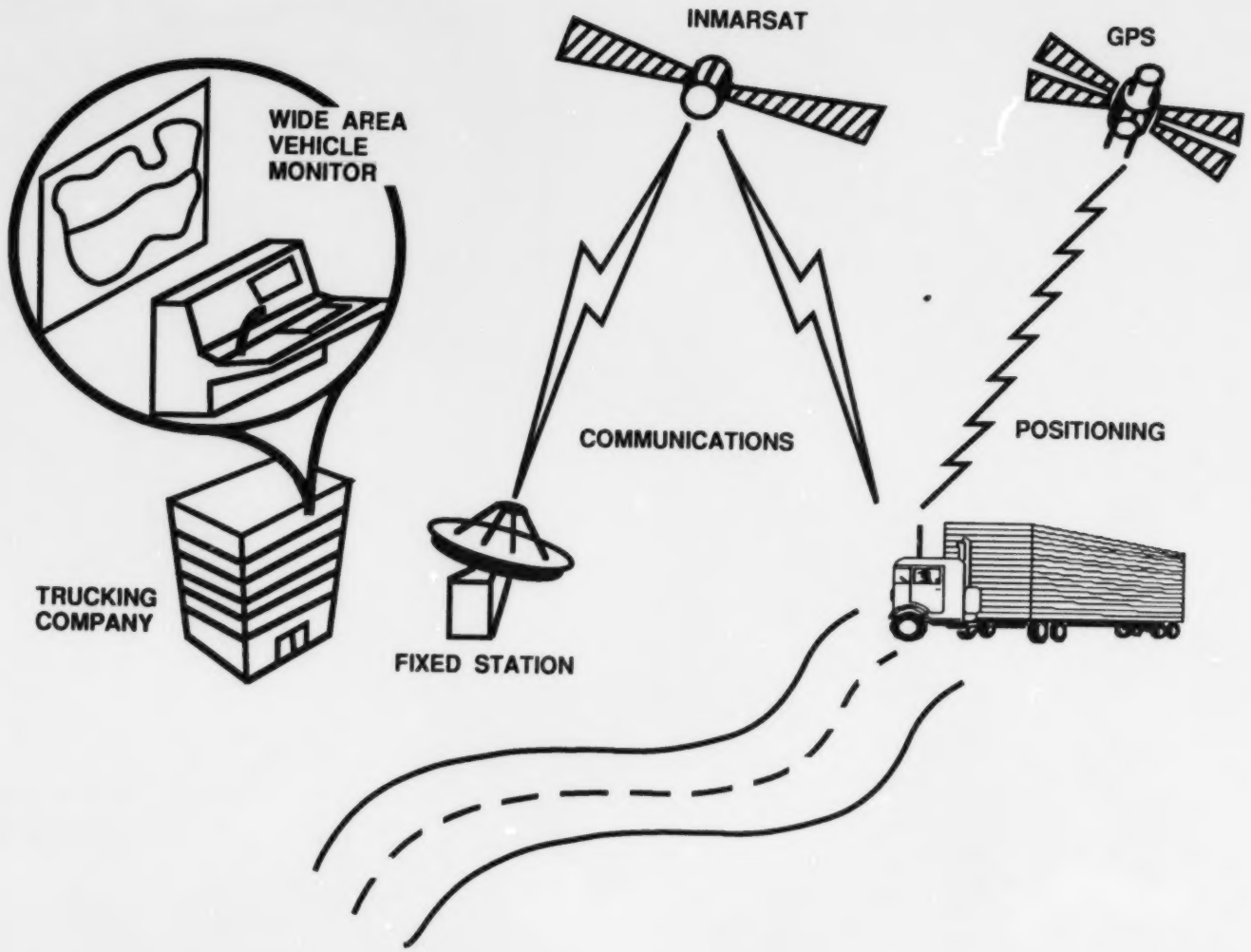
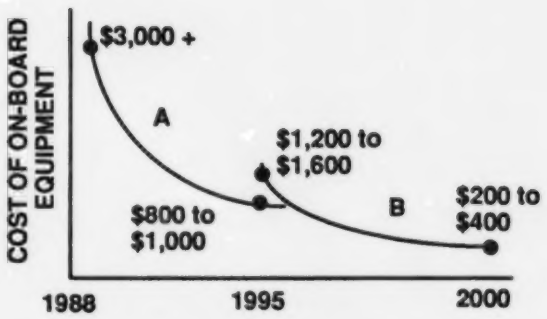


Figure 5/ WAVM/TMI – Road Kit System



A: On-board receiver only

B: On-board receiver plus differential capability and voice and data two ways communication

*** The above are estimates derived from industry sources 1990.**

Source: Thompson-Hickling Aviation Inc.

Figure 6/ Projected GPS Receiver Cost

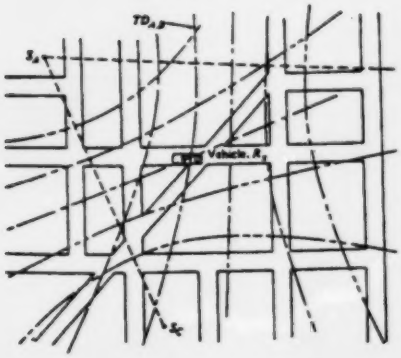
2.4/ Ground-Based Radio Location Systems

Location with ground-based radio systems is obtained by triangulation or trilateration methods using the time difference of arrivals of radio signals. Transmitters continually transmit time-synchronized radio signals, which are picked up by a vehicle's on-board receiver. The time differences of signal reception from at least three stationary transmitters are measured and calculated to give the exact position of the vehicle.

A reverse of the above concept would allow the transmitter in the vehicle(s) to continuously transmit radio signals that are picked up by three stationary receivers for the calculation of positioning coordinates. The calculations may be carried out by the on-board equipment or at the central facility.

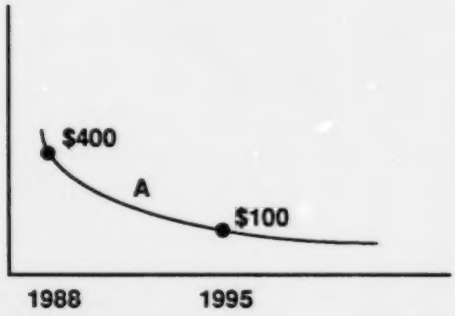
An example of a stationary transmitter is the LORAN-C (long range navigation) system. Initially intended for coastal navigation, LORAN-C has been successfully deployed for land vehicle applications.

LORAN-C is a hyperbolic radio determination system operating at a frequency of 100 kHz. It provides coverage for a fairly large area (>1000 km) with a reported accuracy of 150 metres or better. LORAN-C is geared to provide positioning data and, unless coupled with a communication system, has no autonomous communications capability. The LORAN-C system is government owned and operated, and no user fees are levied. System signals are not affected by multipath or shadowing effects, but are affected by atmospheric and conductivity conditions, which create distortions.



Source: Edward N. Skomal

Figure 7a/ Time-Difference Automatic Vehicle Locating Systems



Source: Thompson-Hickling Aviation Inc.

Figure 7b/ The Probable Evolution of Loran-C Receiver Costs

Low-cost receivers ($550) are currently being marketed, but unless the system accuracy can be improved, their application in urban environments may be difficult to justify.

A modified version of a radio-triangulation system that operates in a reverse mode is currently being marketed by some companies. In this mode, radio signals transmitted from a vehicle are captured by at least three stationary receivers, where calculations are performed, then transferred to the processing centre. This type of system is structured to provide monitoring data. Though the costs of on-board transponders are relatively modest, the costs of the infrastructure are considerable. Two manufacturers offer systems based on this principle using spread spectrum technology: the Australian Quiktrak System and the American Teletrac System. The cost of an on-board transponder (transmitter and receiver) is currently being quoted at $500-600. The reverse radio triangulation system overview is shown in Figure 8. No additional radio equipment is required on the vehicle.

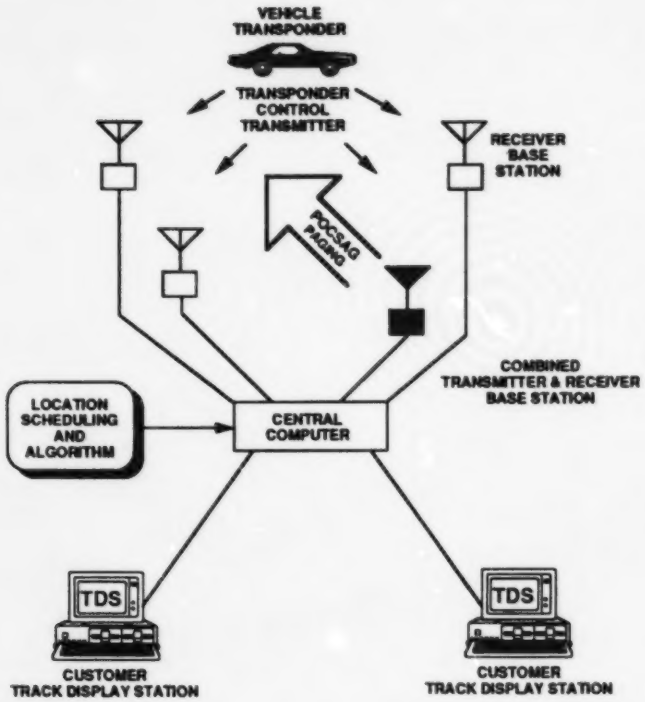


Figure 8/ Reverse Loran (REVLOR) System Overview

2.5/ Hybrid Location Techniques

Hybrid location systems incorporate both the autonomous and non-autonomous systems, offering solutions that may be appropriate on a project-to-project bases. The present technology of automatic vehicle location is not solely based on radio or non-radio location techniques. Many systems do exist that integrate both techniques to overcome limitations inherent to each system type, as well as for redundancy and periodic "fix" purposes.

Table 1 gives an overview of the characteristics of both autonomous and non-autonomous AVL systems described in this section.

2.6/ Comparison of Dispatch and AVL Systems

An overview of dispatch radio and automatic vehicle location systems indicate similarities in their system configurations. Therefore, compatibility between dispatch and AVL systems would pose no problem for a cost-effective integration.

As shown in Figure 9, the basic configuration of both systems consists of a computer centre housed at a central location, base stations, and on-board vehicle equipment.

Table 1/ Comparative Analysis of AVL Systems for Urban Application

Location Systems	User Needs		Accuracy	Coverage		Costs		Current Users
	Position Determination	Central Monitoring		Urban	Constraints	Onboard Equip./Veh.	Additional Costs	
AUTONOMOUS								
DR only	X	optional	tens of metres unreliable	X	error accumulation	approx. $3000	Comm. system + related SW	
DR with Map Matching	X	optional	tens of metres reliable	X	high costs	>$3000	comm. system + related SW + maps	Dept. of Ambulance Services, Toronto, Ont.
Proximity Detection	X	optional	few metres when combined with DR	X	high costs for off-route applications	$550	infrastructure $1000/signpost + comm. system + SW	TTC, Toronto, Ont.
NON-AUTONOMOUS								
Sat. System Active "GEOSTAR"	X	X	currently 1/4 mile with LORAN-C in future 50 m	unreliable	multipath shadow; low update rate	$3500	service charge	US Truck Co.
Sat. System Passive "GPS"	X	optional	50 - 100 m	unreliable	multipath, shadow effect	$700	comm. system central facility	Trial: Dept. of Ambulance Services, Toronto, Ont.
HYPERB. System "LORAN-C" System	X	optional	100 - 150 m	X	atmospheric conductivity noise interference	$700 - 800	comm. system + related SW	Los Angeles, CA
HYPERB. System Reverse Triangulation	optional	X	30 m	X	multipath problems	$500 - 600	infrastructure + SW; service charge	Sydney, AUSTRALIA; Los Angeles, Chicago, Detroit

DR: Dead Reckoning, SW: Software

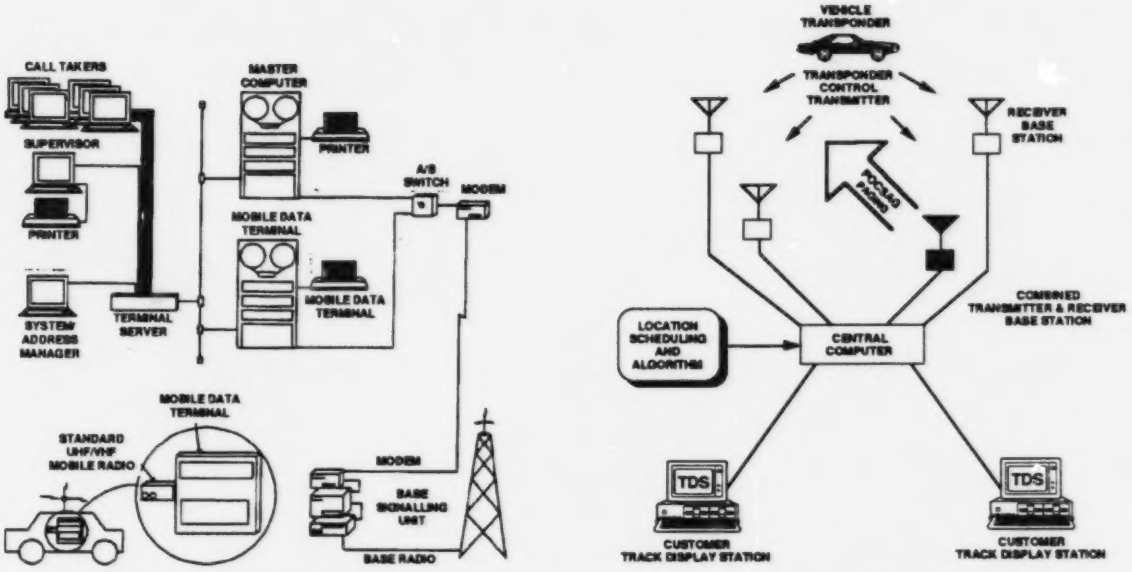


Figure 9/ Similarities Between Cabmate Dispatch and AVL Systems

2.7/ Benefits of an AVL System

The benefits of an efficient automatic vehicle location system are:

- faster response and coordination in life-threatening situations;
- increased fleet efficiency and reduction of fleet operating expenses;
- dynamic scheduling and increased customer satisfaction;
- increased safety and security on the roads;
- increased mobility;
- increased productivity due to fast deployment of closest vehicle;
- efficient operational and management techniques due to effective supervision of fleet activities.

3/ SURVEY OF POTENTIAL USERS

A survey of some 4000 potential users was conducted for this project. The questionnaire used for estimating the present needs and future market potential is in appendices 1 and 2.

In the public sector, questionnaires were sent to municipal departments, ambulance services, the Toronto Transit Commission (TTC), provincial ministries, Metropolitan Toronto Police, Ontario Provincial Police, and the TTC's Paratransit Agency (transportation for the disabled).

In the private sector, taxi companies, tow truck companies, cartage truck/van companies, utilities (hydro), armoured cars, and service companies such as construction and plumbing were sent questionnaires. Table 2 is a summary of the public and private sector market for AVL technologies.

Table 2/ Potential Users of AVL Technology

Public Sector	**Total # of Vehicles**	**Potential for AVL Project**
Metropolitan Police	Approx. 1 200	40
Metro's City Departments	Approx. 1 300	100
Metro Ambulance Dept.	125	125
Toronto Transit Commision (supervisors)	125	125
Ontario Ministry of Transportation (maintenance division)	6	6
Paratransit Agency (transportation for disabled)	100	100
Ontario Provincial Police	1 300	not known
Canada Post	1 200	not known
Business Sector		
Taxi Companies	3 353	2500
Tow Trucks	61	30
Livery Vans	316	50
School Buses		
Cartage	2 949	600
Hydro Utilities		
TOTAL	12 135	Approx. 3686 vehicles

4/ METRO TORONTO'S AVL REQUIREMENTS

Responses to the questionnaires sent to public and business sector organizations and subsequent interviews led to the following definition of user requirements.

Functional Requirements

- positioning;
- tracking (positioning a vehicle at frequent time intervals);
- route guidance (optional).

System Requirements

- Metropolitan Toronto coverage area (680 km^2);
- coverage: urban - 95% downtown; 99% in the rest of the metropolitan area;
- accuracy in downtown core (Eglinton/Dufferin/waterfront/Don Valley) 30-50 metres with a standard deviation of 60 metres;
- response time: < 2 minutes, 85%; 30 seconds, 10%; 2-3 seconds, 5%;
- update rate: 1 second;
- capacity: 10 000 vehicles;
  200 000 emergency and stolen vehicles;
- reliability: 96-99%;
- compatibility with existing dispatching system;
- modular expansion;
- availability: continuous;
- centralized operations;
- multi-user environment;
- number of simultaneous locations per second: 10 or more;
- fixed spectrum allocation with expansion capability.

End User Equipment Requirements

- off-the-shelf equipment (commercial operation);
- cost of on-board equipment not to exceed $550-600;
- easy integration with existing equipment;
- low maintenance costs;
- low monthly service charges.

5/ ANALYSIS OF USER NEEDS

Vehicles in the public sector group are not, with the exception of TTC vehicles and ambulances, equipped with emergency automatic vehicle location systems. Some of these organizations' conventional radio systems are equipped with panic buttons to alert the central facility of an emergency. Potential users' responses to the needs questionnaire and subsequent interviews indicate that a system with location and tracking capabilities is highly desirable. Vehicle monitoring for hazardous goods movement, real-time route guidance, stolen vehicle recovery, and navigation were deemed to be assets, but not priorities.

The business sector group, including taxis, tow trucks, cartage, livery, post office, armoured, and hydro utilities vehicles, is not equipped with automatic vehicle location systems. Their conventional radio systems may also be equipped with panic buttons for emergency purposes.

Some of the large taxi fleet operations have dispatch capabilities, whereby customer requests are dispatched by call takers to taxis according to the pick-up location and respective zone queuing policies. Taxi companies who do not have dispatch capabilities operate in conventional broadcast mode, that is, requests are broadcast to all vehicles in the fleet. Only about 5% of the 700 independent taxis in Metro Toronto are not equipped with any radio system.

Our survey indicates that a system with automatic emergency alert and tracking is an essential feature, but costs must be acceptable. Neither vehicle monitoring navigation or stolen vehicle recovery are deemed to be priorities, but real-time route guidance would be an asset if the price is right. Growth in this sector is expected to be around 5% by 1995.

Summary of Responses:
Highly Desirable Features
- location and emergency tracking capability (deemed essential)
- simultaneous on-demand location capability
- compatibility with dispatch systems
- selective polling capability (each vehicle can be polled separately)
- covert emergency feature
- centralized operations

Highly Desirable Requirements
- cost of on-board equipment not to exceed $600 per vehicle
- monthly service charges not to exceed $15
- small-scale demonstration system

Desirable Features
- stolen vehicle recovery
- real-time route guidance

6/ ASSESSMENT OF COMMERCIAL EMERGENCY LOCATION SYSTEMS

The survey of suppliers of location systems provided valuable information on existing and operational systems, as well as on systems that are currently being prototyped or about to be commercially launched. Some of the criteria were: type of system/equipment offered; availability of the system for immediate or future commercial use; current and future market information; expected installation base; system characteristics; functions and capabilities of the product; results of prototype test and coverage area; product information and estimated costs as made available; and willingness to demonstrate the system in Toronto.

Twelve systems were assessed and evaluated for Metro Toronto application. The systems surveyed included LORAN-C systems, dead reckoning with map-matching augmentation, cellular radio location systems, proximity device systems, and satellite-based systems. Some systems were evaluated on-site, but most were assessed through the documentation made available to us and subsequent consultation with the suppliers of the systems. Key assessment criteria were: availability of the system for immediate application; spectrum availability; specific system characteristics such as accuracy (especially in the downtown core), response time, capacity, reliability, etc.; user costs, i.e., in-vehicle equipment costs and projected monthly service costs; compatibility with existing dispatching or fleet systems; risk assessment; and willingness to demonstrate the system.

The following systems were assessed during the course of this study:
- Quiktrak Location System (Australia);
- Teletrac Location System (U.S.A.);
- Dynamic Transport Management centralized dead reckoning with map-matching location system (V-Trak) (Australia);
- KSI Direction Finding Localization System, Cellular Location System (U.S.A.)
- Marcor GPS Satellite Radio Location System (U.S.A.);
- Locus LAD-LORAN Radio Location System (LORAN-C) (U.S.A.);
- Electronic Integrated System (Canada);
- II Morrow's Detroit Location System (LORAN-C) (U.S.A.);
- Mobile Electronic Tracking Location System (U.S.A.);
- Datatrak Location System (LORAN type) (England);
- Magnavox Navcom Location System (U.S.A.);
- Vehicle Detection System (Proximity Detection) (Australia).

On the short list of the assessment were two systems based on reverse radio triangulation principles. They are the Quiktrak system from Australia and Teletrac System from the U.S. Both systems evolved from their initial application to recover stolen vehicles to a full-fledged vehicle location system with dispatch and emergency capabilities. While the systems operate at different frequencies, their principles of operation are similar and both use spread spectrum techniques to transmit radio signals. The systems are operational in their respective countries and both companies

have shown an interest in installing a system in Toronto. These two systems are recommended for further consideration.

Four other systems, comprised of systems based on dead-reckoning with map-matching, triangulation via radio and satellite signals, and cellular-radio principles, formed the second batch of recommended systems. Because these systems were barely tested in an urban environment, they are recommended for demonstration purposes only. These systems are: V-Trak of Australia (centralized dead-reckoning operation); Marcor GPS of U.S.A.; LOCUS Inc.; LAD-LORAN; and KSI Inc. (cellular systems) of U.S.A.

The remaining seven systems will not be considered for further investigation at this time because, either they do not fulfill Metro Toronto requirements, or because full technical details were not available at the time of assessment.

7/ CONCLUSIONS AND RECOMMENDATIONS

No currently available system meets all requirements at a reasonable cost. To satisfy all requirements, either a redesign of the system or a combination of different system types would be required. Such an approach would increase the total cost of the system, which in turn will ultimately affect the payback projections and the user costs. As the costs fall due to technological advances, an integrated approach may prove to be the best alternative for urban application and still provide a flexible path for future growth.

In the longer term, as system costs fall, a combination of radio location systems and dead reckoning with map matching (or even sign-post systems) certainly holds promise.

In the shorter term, if no immediate action is envisaged, planning for demonstrations of stand-alone or hybrid systems is recommended.

Recommendations:

1/ Proceed with negotiations with companies that would like to demonstrate in Toronto. A joint demonstration using DTM's system with Marcor's GPS receiver and possibly LOCUS Inc. multi-chain receiver should be contemplated. It is expected that funding for such a demo will not exceed $30K.

2/ Continue negotiations with Quicktrac and Teletrac. Best option for the ministry would be to encourage local industry to form a joint venture.

3/ Initiate a feasibility study with a view to incorporate real-time traffic information and route guidance functions in Metro AVL system.

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APPENDIX 1/ NEEDS REQUIREMENTS QUESTIONNAIRE FOR TAXI CABS

Motor Vehicle Location & Communications System

Background Information

Discussions between Ministry of Transportation Ontario (MTO) and The Metropolitan Toronto Licensing Commission (M.L.C.) has led to the initiation of a project aimed at determining the feasibility of an emergency location system for the taxicab industry. Interest from other public service organizations has resulted in their inclusion in the project and expansion of the project scope to include fleet dispatching and navigation and route guidance.

To assist in this project your cooperation in the completion of the attached questionnaire is sought so that we may more fully understand the existing technology currently employed by the taxicab industry.

This questionnaire has been divided into two parts. Part I deals with general existing taxicab communications systems now in use and Part II with specific functions related to Motor Vehicle Location and Communication Systems that may be studied and devised.

Instructions

Fill out the questionnaire by identifying:

a) the user.

b) the use or application.

c) Return the completed questionnaire to L. Gomes, Ministry of Transportation Ontario, Central Building, 3rd Floor, 1201 Wilson Avenue, Downsview, Ontario, M3M 1J8.

TAXICAB INDUSTRY QUESTIONNAIRE
PART I

1. **General Information**

Organization: _____

Contact Person: _____Position_____

Corp. Address: _____

_____

_____

Contact Phone No.: _____Fax No._____

Alternate Contact Person: _____

Position: _____Phone No._____

2. **Type of Service, Size & Coverage**

Do you currently use a communication system? _____

Circle below, category of service and indicate approximate number of vehicles for which your communication system is currently applied.

Category of Service	# of Vehicles
(a) Taxicab	
(b) Disabled Transportation	
(c) Other (explain below)	

Total Vehicles using current Communication System? _____

Other use (Use additional pages if required)

Do your vehicles normally operate outside of Metro? _____

If so, what is the normal radius in kilometers from your communications base site? _____ (approximate kilometers)

TAXICAB INDUSTRY QUESTIONNAIRE
PART I

3. EXISTING COMMUNICATIONS SYSTEM

Describe existing communication system (check as applicable): Yes No

Voice mobile radio system?

Digital radio system?

Combination of the above?

Digital vehicle identification system?

Computerized dispatching system?

Constant transmit from base to mobiles?

Cellular telephones?

Total number of radio channels? _____

Are all channels in use 24 hours per day?

Note: Simplex channel means that base and mobiles transmit AND receive on ONE radio frequency. Duplex channel means that base transmits on ONE frequency but receives messages from mobiles on a different frequency.

Are your radio channels simplex or duplex?

Do you currently have an emergency reporting system in place?

If yes, please detail its method of operation.

_____

_____

_____

Do you currently have any means of locating and identifying vehicles if an emergency should occur?

Are you aware of any other emergency alarms installed in the vehicles with which you communicate?

If yes, please explain:_____

TAXICAB INDUSTRY QUESTIONNAIRE
PART 1

3. Existing Communications System (Continued)

Please describe present base equipment (equipment make, model if known, year, when installed, etc.)

_____

_____

Please provide list of tower or Antennae location(s) and frequencies used at each location (if known):

_____

_____

_____

_____

Do you know the make and model of mobiles used in your system? (Please provide list if known.)

Do the mobiles have fixed channels or are they operator selectable?

_____

4. **Performance**

Circle degree of satisfaction with your present system.

0 1 2 3 4 5 6 7
Dissatisfied Very Satisfied

Provide reasons

_____

_____

_____

_____

5. **Short Term Plans**

Identify any short term plans relative to upgrading of existing system.

_____

_____

_____

_____

TAXICAB INDUSTRY QUESTIONNAIRE
PART 1

6. **Growth**

Indicate the expected growth for the next three years in size of fleet identified in previous item.

_____ _____ _____

7. **Fleet Management Practices**

Briefly describe below your current fleet management practices in terms of:

* Driver reporting
* Dispatch (work assignments)
* Location and monitoring
* Any other relevant Management practices not described.

QUESTIONNAIRE

PART II

INTRODUCTION

Part II of this questionnaire has been divided into 6 (six) functional sections:

1. Emergency Location
2. Communications System
3. Vehicle Location and Status Monitoring
4. Dispatching
5. Navigation and Route Guidance
6. Management Reporting

The following sections are intended to provide you an opportunity to indicate your organisations's needs in the next 5 years. For questions ending in a choice of "Existing, Essential" etc. check the appropriate column. For other questions please provide details

EMERGENCY LOCATION

Definition:

For the purpose of a definition, an emergency is understood to be one of the following:

Red Alert (cannot talk)
Driver in immediate life threatening situation where verbal (voice) communications is deemed inappropriate.

Yellow Alert (can talk)
Driver requires priority access to voice communication (e.g. serious car accident, assault, robbery, etc.).

Blue Alert (can talk)
Driver requires access to voice communication but not on a priority basis (non-emergency situations for example car breakdown-mechanical failure, minor accident, etc.).

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

1. EMERGENCY LOCATION

NEEDS

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	Indication at a control centre of identification and location of a vehicle upon activation of an in-vehicle emergency system (visual display w/colour scheme and taxi number).				
2.	As per supplied definition, specify your alert requirements: - Red Alert - Yellow Alert - Blue Alert - Unspecified Alert				
3.	Continuous monitoring of a vehicle following activation of emergency system (eg. whether motor turned off, stationary or in motion). - Red Alert - Yellow Alert - Blue Alert - Unspecified				
4.	Ability to monitor in-vehicle conversation following activation of red alert system.				
5.	Tampering with an in-vehicle cash drop box to activate red alert.				
6.	The ability to activate the emergency system by the driver when away from vehicle.				
7.	Preferably the monitoring should be performed: In-house Common/Central location Both				
8.	Other (please specify)				

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

2. COMMUNICATIONS SYSTEM

This section deals with voice and data communications between the control centre and the vehicle or between the vehicle and the control centre.

NEEDS

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	Voice Communications				
	(i) Control centre to vehicle.				
	(ii) Vehicle to control centre upon request.				
	(iii) Two-way communications.				
2.	Data Communications				
	(i) Control Centre to vehicle.				
	(ii) Vehicle to control centre (upon request).				
	(iii) Two-way data communications.				
3.	Full communications with hard copy:				
	(i) at control centre				
	(ii) in-vehicle				
4.	Backup communications system in case of main system failure.				
5.	Integration of new system with existing communications system.				
6.	Other (please specify).				

_____

_____

_____

_____

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

2. Communications System (Continued)

Please answer the following questions as briefly as possible or if preferable with yes or no.

7. Are present communications channels (voice, data) operating at or near capacity?

8. Do you have spare channels?

9. Are you planning to upgrade your present system in the next five years?

10. Do you need high reliability/availability of the system?

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

3. VEHICLE LOCATION AND STATUS MONITORING

This section deals with location and status monitoring other than in emergency situations.

NEEDS

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	Location monitoring.				
2.	Second by second monitoring of vehicle location.				
3.	Minute by minute monitoring of vehicle location.				
4.	Hourly or less frequent monitoring of vehicle location.				
5.	Location of vehicle upon control centre request.				
6.	Response time following location request. (SEC.)				
7.	Vehicle location accuracy (METERS).				
8.	Location in covered areas such as tunnels and parking garages.				
9.	Location of vehicles even with engine off.				
10.	Display vehicles in fleet on computerized map display.				
11.	Display day's travel/routes covered by vehicle.				
12.	Control centre monitoring of vehicle conditions. Engine on/off Speed Distance Travelled Engine temperature Taxi meters on/off				
	Other - please specify				

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

3. Vehicle Location & Monitoring
(continued)

Needs

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
13.	Control Centre monitoring of driver initiated status report such as:				
	Life threatening emergency				
	Non-life threatening emergency				
	Mechanical breakdown				
	Fare dispute				
	Require direction				
	Wish to talk to central				
	Other - please specify				

14. Others - please specify

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

4. DISPATCHING

This section deals with dispatching requirements for fleet management purposes. For example, dynamic dispatching, based upon accurate knowledge of the vehicle position at a given time, can contribute to decreases in vehicle response delays and increases in transport load factors, safety and efficiency.

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	Integrate vehicle location system with a vehicle dispatching system.				
2.	Automatic selection and assignment of nearest appropriate type vehicle for service.				
3.	Automatic indication of trip, travel or arrival time for assigned vehicle.				
4.	Automatic selection of optimum route.				
5.	Monitoring of vehicle following dispatch and display of deviation from route or schedule.				
6.	Provision of real time traffic data and road condition information to dispatcher.				
7.	Others - please specify.				

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

5. NAVIGATION AND ROUTE GUIDANCE

Navigation involves the provision to the driver information on his current location. This information can be displayed in a map format on a video screen on the driver's dashboard. The system assists the driver in operating in unfamiliar sections of the city.

Such systems can also indicate the best route to follow from the vehicle's present location to its desired destination. When coupled with real time traffic data such systems could potentially reduce travel time and minimize lost time.

Needs

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	In-vehicle navigation system				
2.	In-vehicle route guidance system				
3.	Real-time traffic information to driver to base				

6. MANAGEMENT REPORTING

This section deals with management practices as applied to the fleet management industry.

Needs

	Functional Requirements	Existing	Essential	Desirable	N.Reqd.
1.	Number of requests for service (i.e. calls per hour/day/week).				
2.	Record of assignment, notification & completion, (i.e. time, date, etc.)				
3.	Unforeseen delays.				
4.	Other (please specify)				

TAXICAB INDUSTRY QUESTIONNAIRE
PART II

Please answer the following questions as briefly as possible.

5. Number of vehicles deployed by day/week. .....

6. Number of dispatched/undispatched messages. .....

7. System downtime, if any. .....

8. Number of emergency situations/call per month/year. .....

7. OTHER CONSIDERATIONS

This space is reserved for additional considerations, suggestions or concerns you may have re MVLCS questionnaire.

APPENDIX 2/ TECHNICAL DETAILS OF THE SYSTEMS LOOKED AT IN THIS STUDY

LOJACK AVL System

LOJACK AVL System (Figure 10) was developed by a small Massachusetts company located near Boston. The system is primarily intended to serve the stolen vehicle recovery market, and hence is geared toward the monitoring function.

When a vehicle equipped with a LOJACK transmitter is reported stolen, the police department confirms that the car is equipped with a LOJACK device and activates the hidden in-vehicle transmitter. The activated transmitter emits signals which are then captured by police cars equipped with a tracker. By homing the police car in the direction of increasing signal strength, the police are able to locate the stolen vehicle.

Because vehicle location is carried out by a roving police vehicle equipped with a tracker and because the time taken to locate the vehicle is unpredictable, the LOJACK system is not suited for emergency and fleet management purposes.

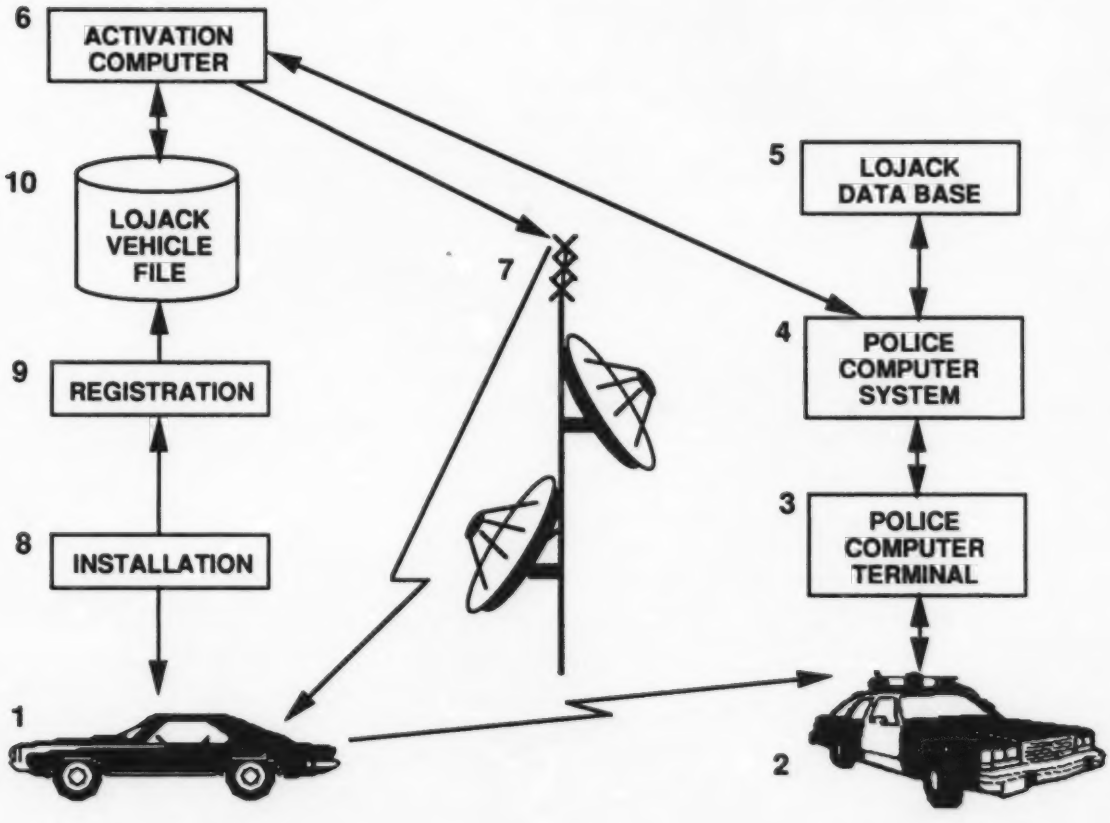


Figure 10/ LOJACK System

QUIKTRAK AVL System

QUIKTRAK is an automatic vehicle location and emergency system developed by Advanced Research Systems of Sydney, Australia. The system works on a radio multi-lateration principle with fixed receiving infrastructures and mobile on-board transponders. QUIKTRAK is based on spread spectrum technology with 2 MHz of channel bandwidth in the 430-450 MHz frequency range. The system is currently operational in Sydney and has evolved from an early engineering model to a commercial system serving approximately 180 customers. A second version is currently being designed to increase its capacity from 33 000 locations per hour to 120 000 locations per hour. QUIKTRAK is an 11-channel system of which 10 operate in scheduled mode for vehicle location purposes and one in unscheduled mode for emergency, alarm, or theft operations.

QUIKTRAK is a stand-alone system, designed for urban applications and geared for monitoring.

Figure 11a shows the elements of the Quiktrak system. It consists of remote towers containing a transponder control transmitter, tracking receiver, timing reference receiver, and a remote site computer. A minimum of three remotes are required to compute the location. There is also a separate remote tower containing a timing reference transmitter. The transponder control transmitter activates the transponder in the vehicle. A hidden switch or button can also activate the transponder in emergency situations. The tracking receiver receives and calculates the time difference of signal arrivals. The timing reference transmitter synchronizes the timing of the signals in the receivers of all remote towers.

The Quiktrak system also has a vehicle transponder, which emits spread spectrum signals upon activation. The operating frequency is 423 MHz and the transmitting power is 1W.

The central computer facility with two VAX processors shown in the figure calculates the vehicle's position ready for transmission to user display terminals. Location request response time is seven seconds, and the subsequent update rate for tracking purposes is one second.

Connections to and from the fixed remote towers to the central facility are made via dedicated telephone lines.

System Features

- 30-metre accuracy with standard deviation of 60 metres;
- Location capacity 120 000 locations/hour (revised version);
- 40 simultaneous location requests per second (revised version);
- Location request response time is seven seconds; update rate is one second;

- A minimum of 10 remote towers would be needed to cover the metropolitan Toronto area;
- Spectrum: 2 MHz bandwidth at 430-450 MHz band;
- Channel definition technique: Spread spectrum, as the name implies, spreads the signal over a wide range of frequencies. Depending on the technique used (direct sequence or frequency hopping) a signal meant for a given user is "tagged" with direct sequence or frequency hopping pattern that only that user's receiver recognizes;
- Cost of an on-board receiver is $550-600 depending on the sales volume;
- Other charges include software fees.

The system is recommended for further consideration.

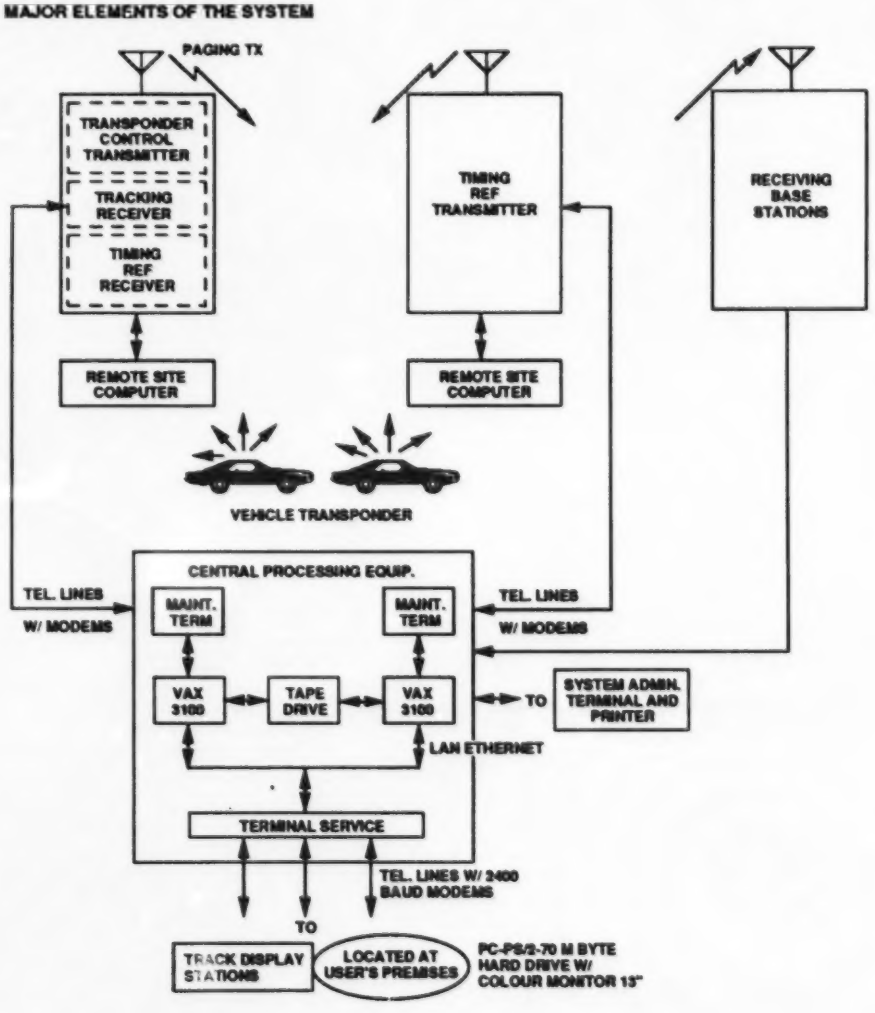


Figure 11a/ QUIKTRAK System

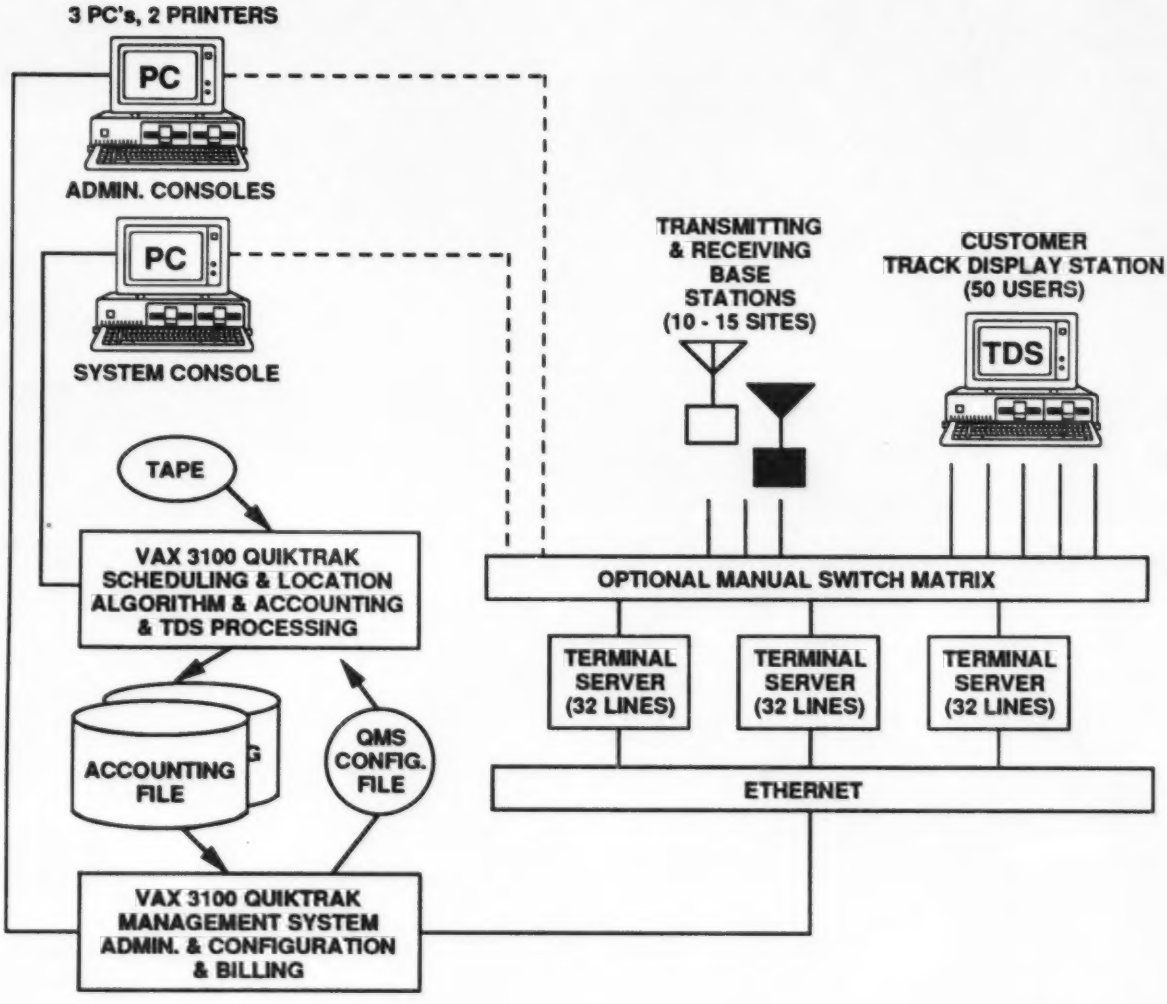


Figure 11b/ QUIKTRAK Central Computer System

Teletrac AVL System

Teletrac is developed by the International Teletrac System Inc. of Los Angeles, California. In principle, the system is similar to Quiktrak as it is based on the radio multilateration technique using spread spectrum technology. The system is currently operational in Los Angeles and the number of users, though officially unknown, is estimated to be large.

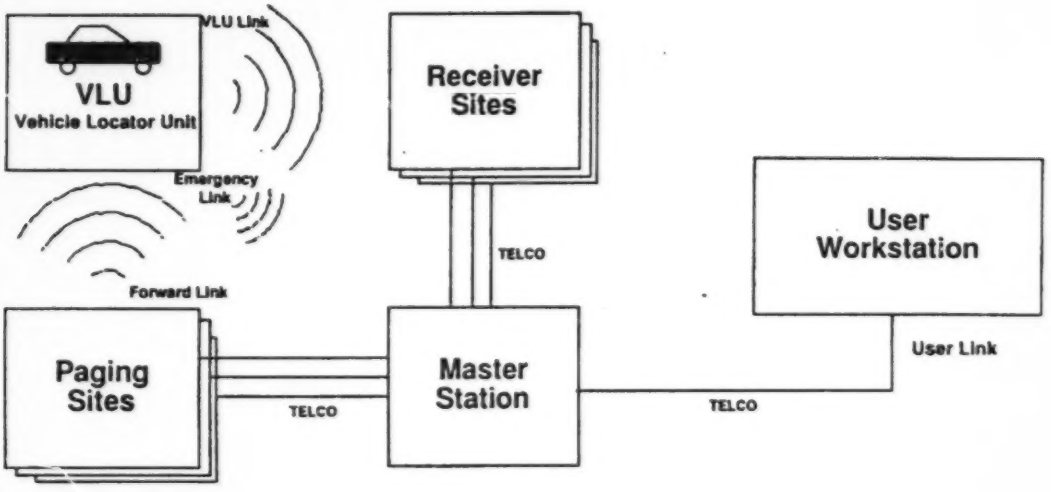
Second and third systems are scheduled to be operational in Chicago and Detroit by 1991 and early 1992 respectively. Teletrac is marketed jointly by International Teletrac System and Pactel (Pacific Telephone Co.). It is a stand-alone system, designed for urban applications and monitoring.

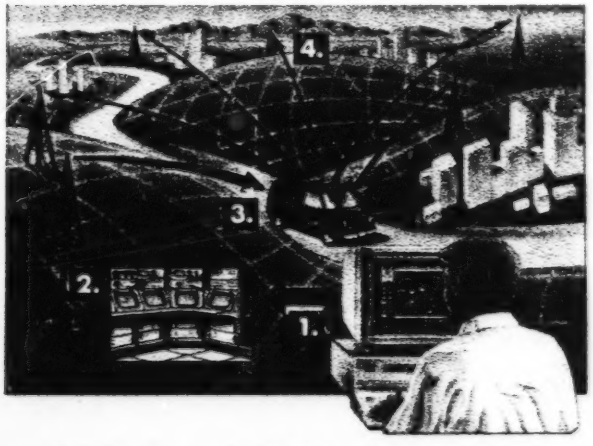
Figure 12 shows the major elements of the Teletrac system, which has a configuration similar to Quiktrak's.

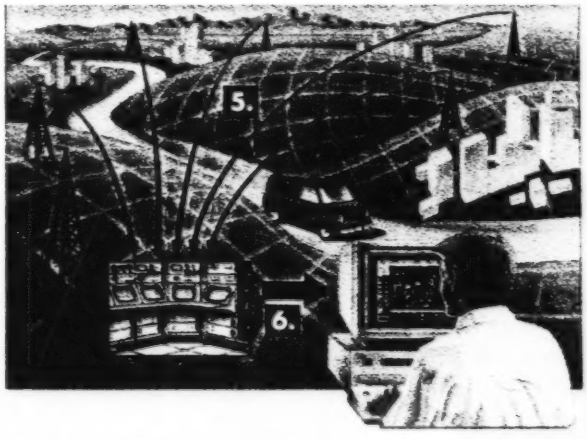
System Features

- Accuracy 30 metres with standard deviation 60 metres (downtown core);
- Location capacity 120 000 locations/hour;
- Location request response time, five seconds; update rate, one second;
- Spectrum 4 MHz bandwidth at 908-925 MHz band;
- On-board transmitter power 5W;
- Channel definition technique: spread spectrum;
- Cost of an on-board receiver is estimated to be $600 U.S. The basic service charge per month is around $40 U.S. for location data.

The system is recommended for further consideration.







1. Dispatcher requests vehicle location.
2. Teletrac Control Center signals paging transmitter.
3. Paging transmitter activates VLU.
4. VLU sends signal to receiving antennas.
5. Receiving antennas relay signal to Teletrac Control Center.
6. Control Center calculates and forwards vehicle location to dispatcher.

Figure 12/ Major Elements of the Teletrac System

DATATRAK AVL System

Datatrak is developed by Datatrak Ltd. of Surrey, England. The system is based on the LORAN-C principle, but it's not government owned as in North America. The system is currently operational in England. The reported accuracy is 50 metres over 95% of the time in a coverage area. No details of its accuracy are available from London city area or in any other urban area. The Datatrak system (Figure 13) is geared primarily to provide positioning data, which are relayed to the central facility via a radio and a data communications network. Transmitters have been installed throughout England at 150 km intervals, which guarantees 95% coverage, 95% of the time. Due to the high cost of its infrastructure, data communication, and on-board equipment, as well as lack of performance specifications for large urban areas, the Datatrak system will not be recommended for further consideration.

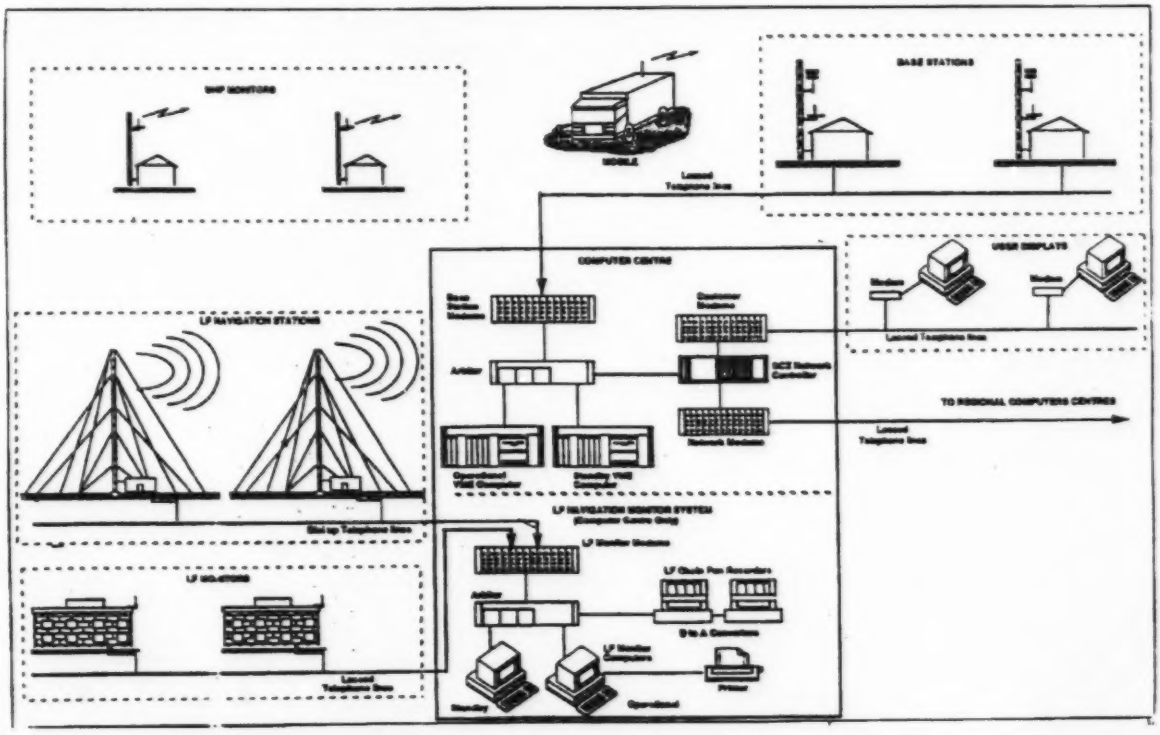


Figure 13/ DATATRAK System

Detroit Police AVL System

Detroit's AVL system (Figure 14) was developed by II Morrow Inc. of Oregon, Ohio. The system was installed for the Public Safety Department (police, fire, and emergency medical services) of Detroit in 1988. The system is based on LORAN-C location techniques, and is therefore structured to provide positioning data. Location information calculated and stored in the on-board receiver/computer is relayed back to the central facility (dispatch centre) via a radio communications system.

The system has been operational for some time. Because of its poor accuracy (660 ft, 90% of the time over the coverage area), the system does not justify further consideration.

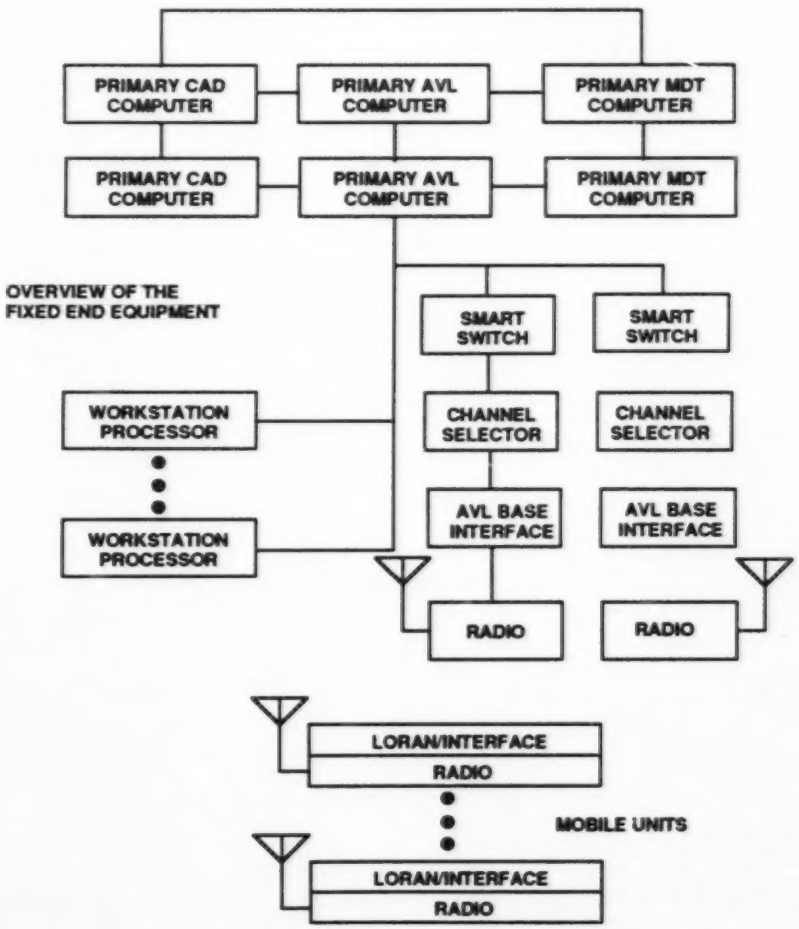


Figure 14/ Detroit AVL System

Marcor's AVL System

Marcor Inc. of Washington, D.C. is currently marketing a relatively cheap, palm-sized receiver (Figure 15) which would capture signals transmitted by the GPS satellites. The receiver may be used effectively for urban and non-urban location applications. According to Marcor's executives, the GPS receiver has been designed to receive signals from as many as eight satellites. This type of system is geared to positioning. A two-way communication system would be required to configure the system for the monitoring function and centralized operations. Initial tests with Marcor's GPS receiver (Hummingbird) in the state of Virginia indicated that an average of 50-metre location accuracy was obtained. The cost of the receiver is estimated to be around $550 for quantities above 1000. The Hummingbird receiver has been designed to be compatible with analog radio systems. Negotiations to test the reliability of the Hummingbird receiver in Metro Toronto are currently under way. Marcor's system is recommended for further investigation.

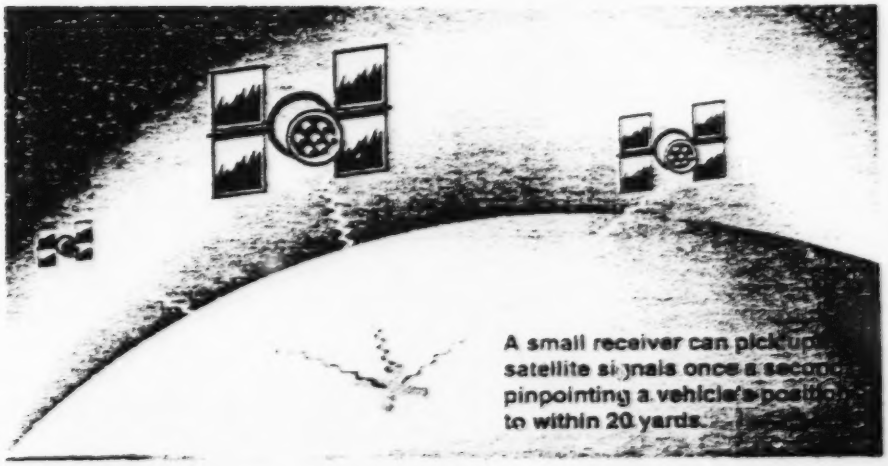


Figure 15/ GPS Location Technique

V-trak AVL System

V-trak (Figure 16) is an AVL system developed by Dynamic Transport Management Pty. Ltd. of Melbourne, Australia. The system is based on the dead reckoning principle, hence geared toward the positioning function. The on-board equipment consists of a digital trip recorder which records and stores the vehicle's movements (positions). The stored data are then relayed to the central facility for further calculation and display of the exact location of the vehicle through sophisticated map matching techniques. Dynamic Transport Management has submitted a proposal to MTO for a small-scale demonstration project, in conjunction with a GPS receiver. The cost of on-board equipment with GPS receiver is estimated to be less than $1500. The system is recommended for further consideration.

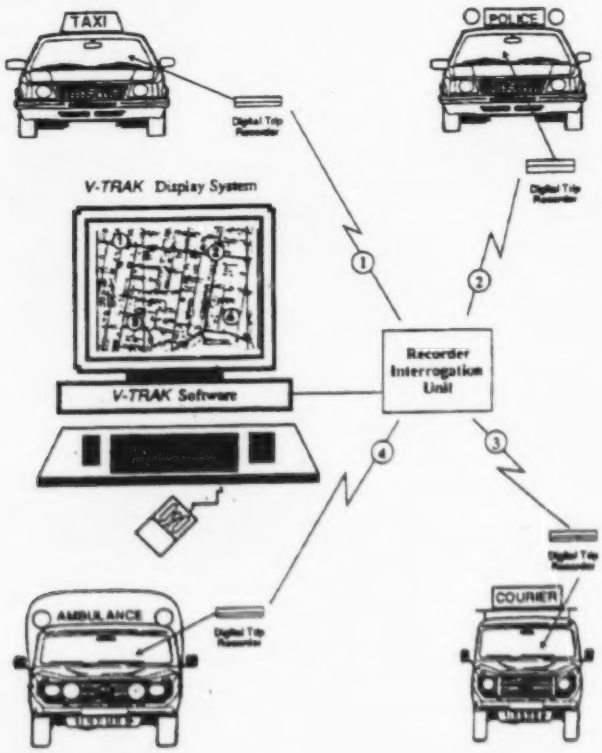


Figure 16/ V-Trak System

Mobile Electronic Tracking (MET) System AVL System

Mets Inc. of Indianapolis, Indiana is a system provider in the AVL business world. Mets's expertise lies in accommodating its proprietary location and tracking software and display technology to any type of location system already mentioned in this report. Currently Mets is also marketing an on-board 900 MHz transponder for AVL applications with expected accuracy of 15 metres. Since no detailed technical information is available at the time of this writing, Mets location system will not be considered for further investigation.

LOCUS AVL System

LOCUS Inc. of Madison, Wisconson is currently developing a unique linear average digital LORAN-C system. Extensive tests both for urban and non-urban applications indicate that the performance of the LOCUS receiver is equal or superior to the currently marketed GPS receiver. Reported accuracies are less than 60 metres in normal mode and 5 metres in differential mode. Better accuracies are expected with its new multi-chain receivers. The company guarantees complete coverage for Toronto. The projected cost for a LOCUS receiver is $500-700 U.S. The company is interested in testing its new multi-chain LAD LORAN-C receiver in Toronto as soon as its data tests are completed. To date, extensive tests were carried out for long-haul trucking and urban applications such as buses and delivery vans, using the single-chain (first generation) receivers. Test results indicate excellent accuracy in urban applications.

The system is recommended for further investigation.

Direction Finding Localization System (DFLS) – KSI Inc. – Annandale, Virginia

DFLS (Figure 17) exploits the concept of a cellular technology for vehicle location and tracking. DFLS uses the signal transmitted from an in-vehicle cellular telephone to provide the basis for vehicle location. The company's technical experts report that multipath problems particular to densely built-up city areas have been successfully resolved. DFLS uses the control channels of the cellular system to transmit digital information. Since more than one cell site can capture signals from the phone, angles of arrival of these signals at the receiving sites (cell sites) can be calculated and the location determined through directional intersection. DFLS can either be a stand-alone system or overlaid onto a cellular network. The cost of on-board equipment (cellular phone or a similar device) is expected to be approximately $400-700, and the cost per cell site approximately $90,000.

The system could be recommended for further investigation should further technical details be made available.

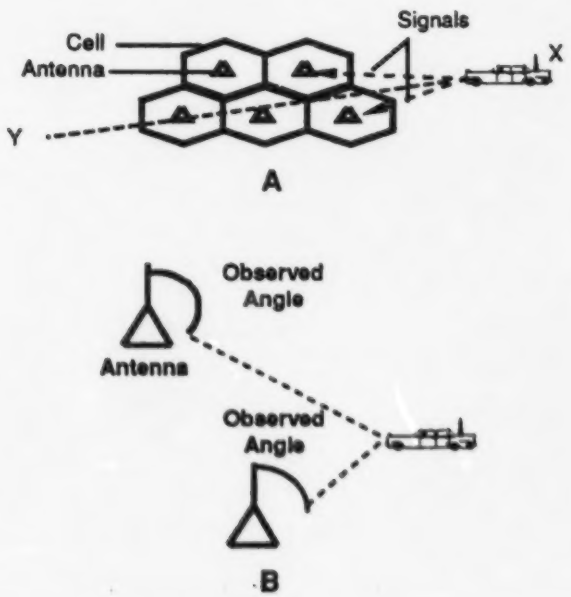


Figure 17/ DFLS Conceptual Overview

AVL Demonstrator

Electronic Integrated Systems (EIS) of Toronto has proposed to develop a cost-effective AVL system for Metro Toronto if funding to develop the system is made available by the ministry.

The proposed system would determine the location of the vehicle through the trilateration method, using the differential time of arrival (DTOA) principle. Coded signals emitted from a vehicle are captured by several remote receivers where they are decoded and time stamped. These data are then relayed to a central computer facility where the location of the vehicle is determined and displayed on the screen or recorded on a hard copy. The cost of an in-vehicle unit is expected to be approximately $300. The estimated costs of a remote site is approximately $100,000. The system is recommended for further consideration.

The AVL system as proposed by EIS, is illustrated in Figure 18.

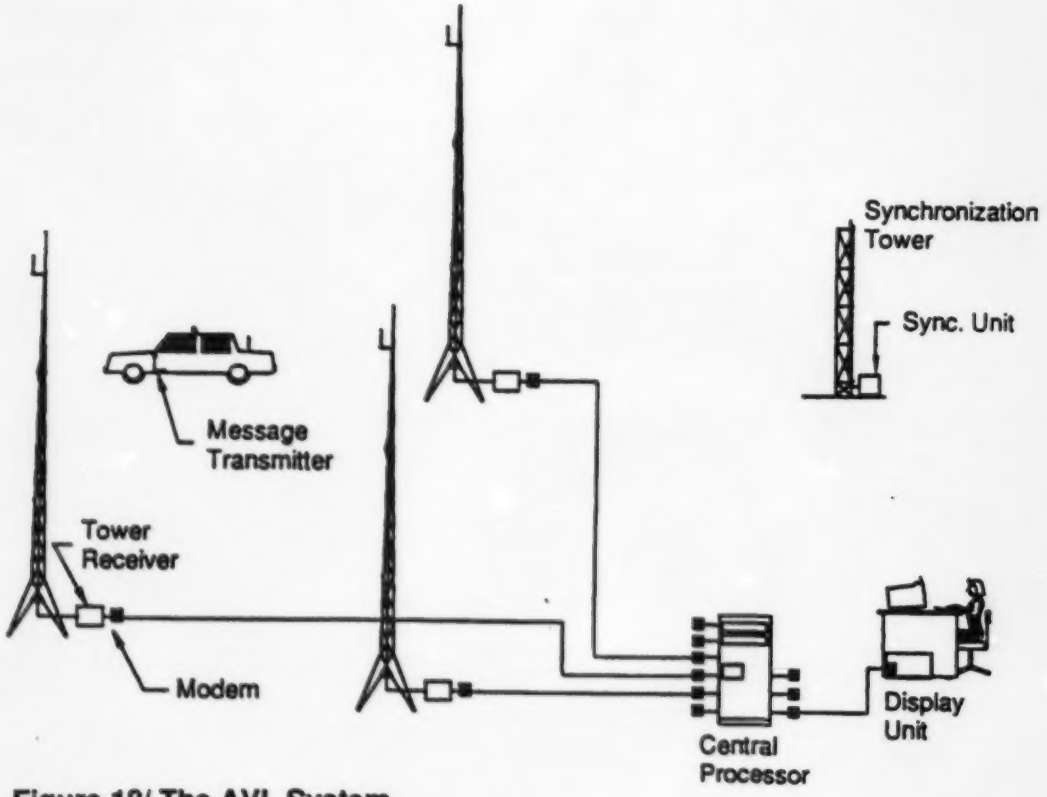


Figure 18/ The AVL System

Vehicle Detection System (VDS)

Advanced Systems Research of Sydney, Australia developed the VDS for the Roads and Traffic Authority Department of New South Wales, Australia. In essence VDS is a vehicle identification system designed specifically to monitor vehicle transmitting through traffic nodes for the collection of travel-time statistics. VDS is a two-way system consisting of an electronic tag (in-vehicle transponder) and an interrogator (wayside transmitter-receiver unit). The interrogator activates the tag, collects the vehicles ID and time and relays this information via the node to the central computer site. A system configuration of this type could be used for urban vehicle location purposes provided the existing infrastructure post (traffic light, hydro, telephone etc.) could be used to install an interrogator. The cost of an interrogator is estimated at around $2000.

The system is recommended for further investigation. Figure 19 illustrates the concept of VDS System.

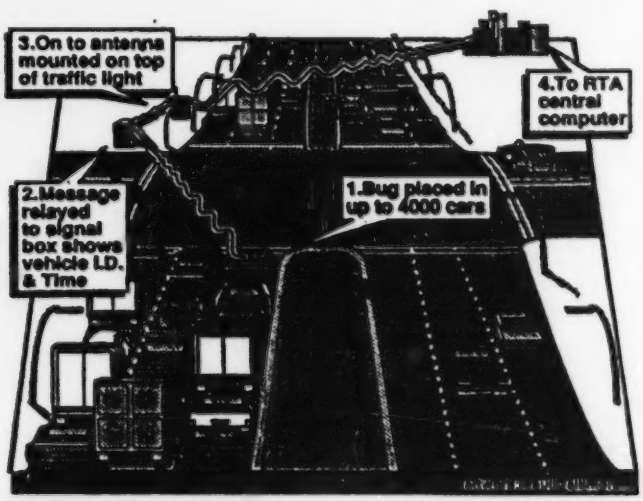

3.On to antenna mounted on top of traffic light
4.To RTA central computer
2.Message relayed to signal box shows vehicle I.D. & Time
1.Bug placed in up to 4000 cars

Figure 19/ The Australian VDS System

NAVCOM Inc. (MAGNAVOX) AVL

Contracted by the Department of Ambulance Services in Toronto, the NAVCOM System was installed and field tested in Toronto (1989-1990). The system consisted of a combination of non-autonomous satellite, Global Positioning System, and an autonomous dead reckoning system. The positioning information collected in an on-board receiver was relayed via a VHF radio system to the ambulance's dispatch centre for an immediate update of selected vehicle locations. The cost of the Magnavox GPS receiver used in this demonstration is about $7000.

The system (Figure 20) is not recommended for further investigation because its performance in the downtown area was unsatisfactory due to multipath and shadowing problems.

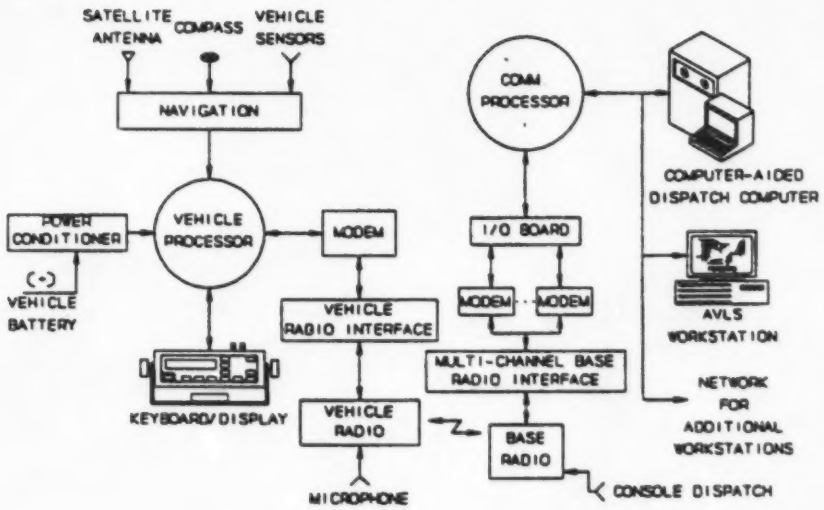


Figure 20/ System Block Diagram for Metro Ambulance Services

APPENDIX 3/ NEEDS REQUIREMENTS QUESTIONNAIRE FOR TAXI CABS

SUMMARY OF TAXI INTERVIEW FINDINGS

	Metro Cab	Diamond Taxi	Co-op Cab	Becks Taxi	Royal -A- Kwik	Scarboro Taxi	Maple Leaf	Zaks Taxi	Indep. Cab Assoc.	Other
No. of Vehicles	730	560	400	240	200	100	55	40	670	358
Radio System	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes/No	–
Operating Frequency	VHF	VHF	VHF	VHF	VHF/UHF	VHF	VHF	↑		
System Performance	S	S	S	S	G	P	G			
Interference	Yes	Yes	Yes	No	No	No	No	See DT		
Communications	V	V + D	V + D	V + D	V + D	V	V + D	↓		
Mobile Terminal Own/Rent	Yes/Yes	Yes/Yes	Yes/Yes	Yes/–	Yes/Yes	Yes/Yes	Yes/Yes		?	
Existing Emergency Feature	–	PB	PB	PB	PB	–	PB	PB	?	–
Need for Auto. Location	V	V	V	V	V	V	?	?	?	?
Need for Auto. Emergency & Tracking	V	V	V	V	V	V	V	V	V	V
Need for Route Guidance or Navigation	–	–	–	–	?	–	?	?	?	?
Ceiling for AVLE On-board Equipment (max.)	>$500	>$600	>$600	$550	$600	$500	$600	?	$500	$500 +
Service Charge $/mi	>20	>25	>25	>25	>30	>20	>25	>20	>20	?
Expected Growth 1995	15-20/veh	215	20	72	150	200	200	–	–	
Agree with Questionnaire and Interview	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demonstration	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

S: satisfactory; G: good; P: poor; PB: push button; V: voice; V + D: voice and data; DT: Diamond Taxi;
Other: Tow trucks, Cartage, Paratransit, Toronto Transit Commission, etc.

NOTE: Information collected in early 1990.